DESIGN AND OPERATION OF THE SUPERIBEX ACCELERATOR AT THE NAVAL RESEARCH LABORATORY[a]

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Abstract: The Naval Research Laboratory has designed and built a new accelerator based on the Isolated Blumlein concept.[1,2] The new accelerator called SuperIBEX is to be installed in the new Charged Particle Beam Propagation Laboratory at NRL. The accelerator is designed to generate a single 5-MV, 100-kA, 40-ns FWHM pulse with zero prepulse. The e-beams produced by this accelerator will be injected into pre-formed and beam-generated channels to study CPB propagation physics. The design of the accelerator and Transmission Line Code simulations of the system operation will be presented.

INTRODUCTION

The SuperIBEX pulsed power generator was designed to produce 5-MV, 100-kA electron beams for Charged Particle Beam propagation research at the Naval Research Laboratory. It will be the primary pulsed power generator in a new laboratory being established at NRL. The laboratory construction began in August 1986 and is expected to be complete by September 1987. The SuperIBEX generator and all the components have been constructed and delivered to NRL and await installation in the new laboratory. During the interim the diagnostics have been installed in the new accelerator and diode hardware has been fabricated in preparation for bringing the system on-line. In addition modeling of the expected accelerator output has been continued in a effort to characterize the operation of the system. Testing of the accelerator and comparisons of the results with computer predicted output will be reported at a later time. This paper will detail some of the design criteria for the new system and some of the modeling performed to date.

SuperIBEX AND THE ISOLATED BLUMLEIN CONCEPT

SuperIBEX is the latest in a series of Blumlein pulse forming networks based on the Isolated Blumlein concept[1,2] developed at Sandia National Laboratory. It is modeled after the IBEX (for Isolated Blumlein Experiment) accelerator at Sandia with somewhat higher output voltage and longer pulselength. The fundamental difference between the Isolated Blumlein (IB) and a Conventional Blumlein (CB) is the use of a segment of transmission line to isolate the output switch(es) from ground for the duration of the accelerator pulse rather than a lumped element inductor as in the CB case. This allows the IB to be charged through a relatively low inductance transmission line rather than a lumped circuit inductor which effectively eliminates any prepulse on the load during the charging of the line. The cost of this lack of prepulse is the loss of 50% of the stored energy in the Blumlein.

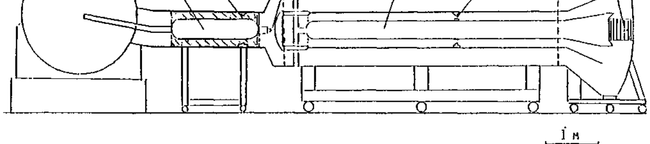

FIGURE 1. SuperIBEX Generator System.

The SuperIBEX system is comprised of four main components (see Fig. 1). These are the Marx generator, a water capacitor/divert switch section, the Isolated Blumlein, and a vacuum diode. The Marx consists of 26 stages of two 2-μF capacitors connected in series which can be charged in a bi-polar manner to $\pm$60 kV. Fully charged the Marx stores 187 kJ. The entire Marx is insulated in transformer oil. The Marx was built by Maxwell, Inc. and formerly powered the Maxibeam 3-60 system used by Austin Research Associates for electron beam production experiments. It has been upgraded with the addition of 4 more stages and the appropriate switches. The first 3 stages of the Marx are triggered by a 350-kV pulse and the remainder are self-triggered. The Marx and output connection have a total inductance of 13-μH. An oil insulated inductor connects the Marx through a dielectric interface to a 60-ns long, 3.9-ohm water filled coaxial capacitor. A two-gap water-filled divert switch is located on the downstream side of the water capacitor to protect the Marx from the pulse reflected from the load. The water capacitor is connected through a diaphragm into a single-electrode coaxial oil switch. An arrangement of six axial rods connects the back of the oil switch to the intermediate coaxial conductor of the Blumlein. The inner conductor is rigidly connected to the outer conductor with six rods extending radially between the axial conductors. The inner and outer coaxial oil-insulated 27-ohm transmission lines are supported by a diaphragm at the diode end. A six-location self-break oil switch is located between the intermediate and inner conductors halfway down the inner 40-ns long coaxial transmission line. The end of the inner conductor is connected to one end of a "Z-stack" diode insulator. A cathode is attached to the inner conductor and cantilevered down the axis in the vacuum region to an anode plate connected to the outer conductor. The entire line was designed to operate at less than 70% of the self-break voltage for negative polarity output pulses.[3] Into a matched 54-ohm load impedance the Blumlein should produce a 40-ns FWHM, 5.0-MV output voltage pulse for a $\pm$50-kV charge on the Marx capacitors.

SuperIBEX TRANSMISSION LINE CODE SIMULATION

The SuperIBEX generator system was designed by NRL with the assistance of Sandia National Laboratory personnel. Prior to the design and construction of the accelerator the entire system was modeled extensively using a combination of the electrostatic field plotting code and the transmission line code.[4] The results of the TLC modeling were then coupled with electrostatic field plots of critical areas within the pulse line to determine the final design of the hardware. The generator has been built and will be installed in its laboratory during September 1987. Prior to the initial experimental testing of the accelerator the TLC offers an opportunity to predict the voltage and current waveforms at different locations within the accelerator. These can then be compared with the measured waveforms during the operation of the system. Three examples of the TLC modeling using the final design parameters of the system are included in this paper. First the basic waveforms for a matched load impedance case are shown, second the peak voltage as a function of load impedance is illustrated and finally the effect of output switch inductance on the matched load waveform is detailed.

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14. ABSTRACT
The Naval Research Laboratory has designed and built a new accelerator based on the Isolated Blumlein concept.1 â¢ 2 The new accelerator called SuperiBEX is to be installed in the new Charged Particle Beam Propagation Laboratory at NRL. The accelerator is designed to generate a single 5-MV, 100-kA, 40-ns FWHM pulse with zero prepulse. The e-beams produced by this accelerator will be injected into pre-formed and beam-generated channels to study CPB propagation physics. The design of the accelerator and Transmission Line Code simulations of the system operation will be presented.

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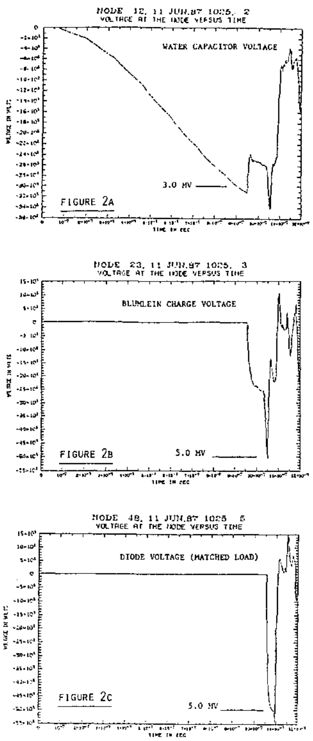

FIGURE 2. SuperIBEX TLC Simulation.

SuperIBEX WAVEFORMS WITH A MATCHED LOAD

The Marx generator, when fully erected, has a 38.5-nF capacitance and produces 2.6 MV when the 26 stages are charged to ±50 kV. The water capacitor and Isolated Blumlein were designed to operate at this Marx charging level. When the Marx is used to charge the ~4-ohm, ~60-ns long water capacitor through the 13-μH distributed inductance of the Marx and the output connector a degree of voltage 'ring-up' is obtained due to the differences in the capacitances. Figure 2a shows the expected voltage waveform at the downstream end of the water capacitor. The oil switch separating the water capacitor from the Blumlein is set to fire at 3.1 MV in the simulation which occurs at 950 ns after the Marx trigger. This is somewhat before the water capacitor voltage has reached its peak. When the oil switch closes the water capacitor begins to charge up the intermediate conductor of the Isolated Blumlein. The use of the water capacitor and the low inductance feed of the Isolated Blumlein allows a rapid charge of the intermediate conductor. This raises the self-break electric field significantly and allows a more compact design to be used. Figure 2b shows the voltage at the upstream end of the Isolated Blumlein on the intermediate conductor. The voltage pulse begins after the oil switch has fired. It takes 80 ns to charge the 40-ns long inner and outer coaxial transmission lines surrounding the intermediate conductor to ~5 MV. After the lines are fully charged the 6 self-break oil gap switches which comprise the output switch are set to close. 20 ns after this switch closes the voltage wave arrives at the diode load impedance resulting in the load voltage waveform shown in figure 2c. The load waveform is ~40-ns wide with a peak of ~5.0 MV. An expanded view of the output waveform is shown in figure 3. The waveform has a 40-ns FWHM with a ~10-ns risetime and a nearly flat top. The prepulse, as discussed in a later section, is less than ±200 V during the charging of the Blumlein.

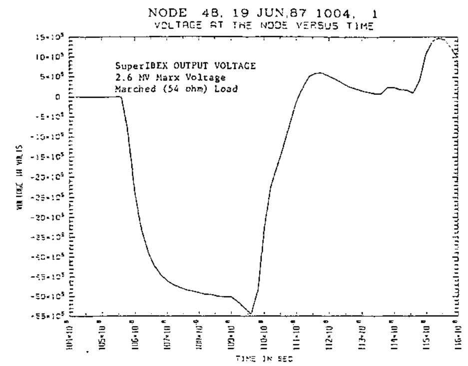

FIGURE 3. SuperIBEX load voltage waveform for a matched load.

LOAD IMPEDANCE DEPENDENCE

One of the benefits of the Isolated Blumlein is a lack of output waveform dependence on the impedance of the diode load (assuming a constant load impedance). In a Conventional Blumlein as the diode impedance increases the lumped element inductor will shunt a fraction of the current from the load. The output waveform in an Isolated Blumlein is determined primarily by the output switch and the design of the forward half of the inner and outer Blumlein transmission lines. For a given output switch inductance the amplitude of the load voltage will depend on the diode load impedance. In order to test the load impedance effect a series of different constant load impedance cases were run with the TLC. The waveshapes over the range of 0-120 ohms were similar to that shown in figure 3 for the matched (54-ohm) load. Figure 4 shows the dependence of the diode load voltage on the load impedance. Note that for a 120-ohm load impedance the diode voltage can approach 7 MV.

OUTPUT SWITCH EFFECTS

The output waveform in the IB can be affected by the output switch inductance. The 6-gap output switch used in the model has ~50-nH inductance. This results in the ~10-ns risetimes illustrated in figure 3. If only a fraction of the six switches close at the proper time then the inductance will increase. The effect is to slow the risetime of the output waveform and to lower the peak load voltage. Figure 5 shows three cases where a 54-ohm load was driven by the Isolated Blumlein with 6, 4, and 1 of the gaps closing (inductances of 50, 75, and 300 nH respectively). As the inductance increases the risetime of the load voltage increases and the peak voltage

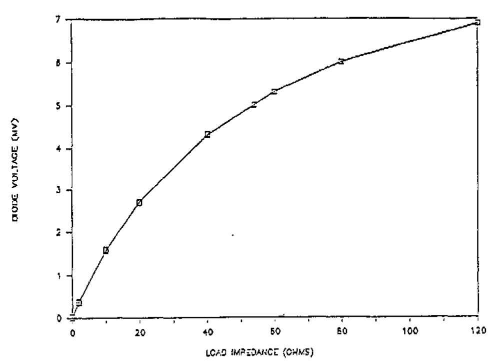

FIGURE 4. SuperIBEX load voltage as a function of load impedance.

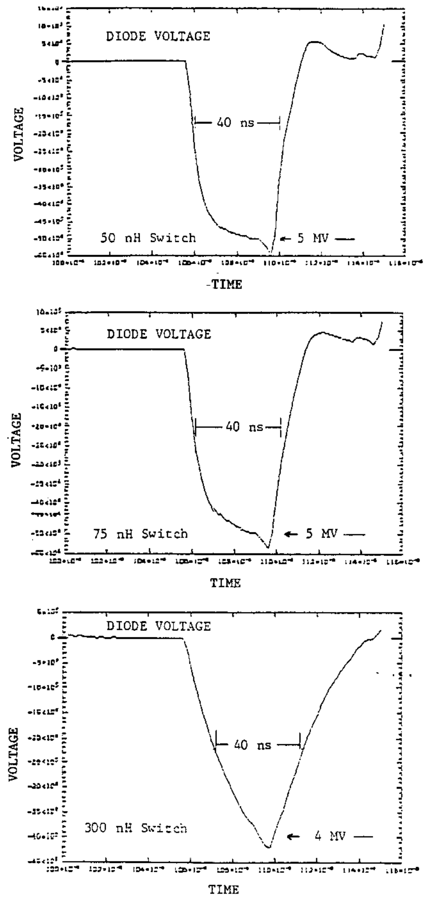

FIGURE 5. Load voltage dependence on output switch inductance.

decreases. A single gap firing gives a 40-ns risetime and a nearly triangular pulse shape with just over 4-MV peak voltage. This illustrates the importance of adjusting the six switches to close on every shot.

ISOLATED BLUMLEIN PREPULSE SUPPRESSION

One of attributes of an Isolated Blumlein pulse forming line versus a Conventional Blumlein is the lack of prepulse appearing across the load during charging. This is the result of how the intermediate conductor is charged in the IB versus in the CB.

In the Conventional Blumlein case (see figure 6a) the inner coaxial transmission line region of the Blumlein pulse line is charged through an inductor connecting the inner conductor to ground. This inductor is designed to provide a ground for the inner conductor on the Marx charging timescale but to have a high impedance relative to the load impedance (Z_{load}) on the timescale of the Blumlein output pulse. The inductor effectively isolates the inner conductor and the output switch from ground for the duration of the output pulse. The Blumlein charging timescale (τ_{marx}) is set by the Marx and its series inductance while the output timescale (τ_{load}) is set by twice the electrical length of the Blumlein transmission line. This translates into the equation

$$L/\tau_{marx} << Z_{load} << L/\tau_{load}$$

for optimum CB operation. For a pulsed power generator with $\tau_{marx} \sim 1$ μsec and $\tau_{load} \sim 50$ ns as in the SuperIBEX case and a load impedance $Z_{load} \sim 50$ ohm, the inductor has to be ~3 μH to satisfy both conditions. In most cases compromises are necessary and the inductor does not act like a perfect ground during the charging of the intermediate conductor. Higher frequency transients in the charging circuit and the small but finite impedance of the inductor lead to some voltage across the inductor. This usually oscillatory voltage appears across the load impedance as a prepulse and can be a significant fraction of the output voltage.

The Isolated Blumlein design (figure 6b) eliminates the need for the large inductor. The output switch in the IB case is located between the inner and intermediate conductors in the center of the coaxial transmission line. When the switch closes it is isolated from ground for the length of the output pulse by the transit time of the transmission line rather than the high impedance of the inductor as in the CB case. Without the necessity of the inductive isolation of the inner conductor and the output switch the inner and outer coaxial transmission lines can be charged through the relatively low inductance of the transmission lines. This low inductance results in a decrease of several orders of magnitude in prepulse voltage over the CB case during the charging of the Blumlein.

As an example of the difference between a Conventional Blumlein and an Isolated Blumlein a simple Transmission Line Code simulation of the two cases was run. Both TLC simulations used a 38-nF Marx erected to 1 MV, charged the Blumleins through a 50-μH inductor, and had a 50-ohm load impedance. The CB case used two 20-nsec long sections of 25-ohm line and a 3-μH isolation inductor as illustrated in Fig. 6a. The IB case used two 20-nsec long

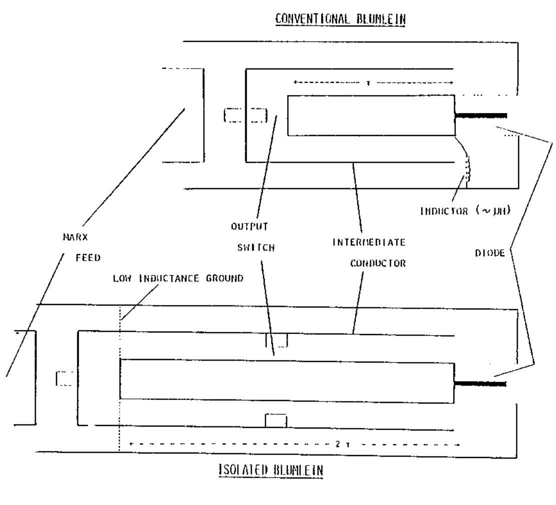

FIGURE 6. (a.) Conventional and (b.) Isolated Blumlein schematics.

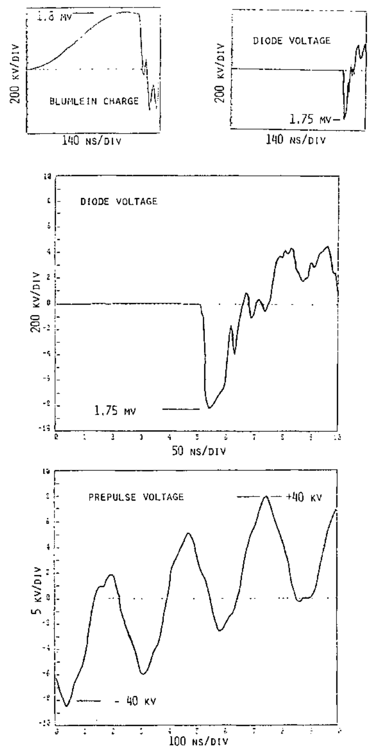

FIGURE 7. Blumlein charging voltage, diode voltage, and prepulse voltage for a matched load impedance for a Conventional Blumlein.

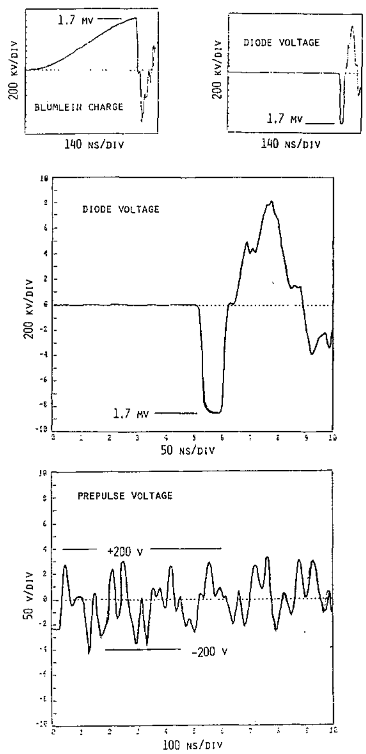

FIGURE 8. Blumlein charging voltage, diode voltage, and prepulse voltage for a matched load impedance for an Isolated Blumlein.

segments of 25-ohm line and an additional 20-nsec long, 25-ohm segment to isolate the output switch from ground during the output pulse. The output switches were fired 1.14 μsec after the start of the simulation. The results of the TLC simulations shown in figures 7 and 8 show both types of Blumleins to charge to approximately 1.7 MV after ~1 μs. The output 40-nsec pulse widths are both determined by the double transit time of the 20-nsec long sections of pulse line. The 1.7-MV output diode voltages are similar but the prepulse levels are markedly different. The Conventional Blumlein case shows a $\pm$40-kV oscillatory waveform lasting over the entire ~1-μsec charging time while the Isolated Blumlein case shows an almost negligible higher frequency oscillatory prepulse of $\pm$200 V. The Conventional Blumlein prepulse is large enough to produce localized emission off a field emission vacuum cathode. This emission can result in localized plasma hot spots which can expand over the 1-μsec time span before the output pulse and significantly affect the diode symmetry and/or impedance.

Conclusions and Acknowledgements

The SuperIBEX generator has the potential to become a valuable tool for studying CPB physics at NRL. The many hours of work by the technical staff at NRL involved in bringing this project to its present state deserve special recognition. The assistance of Juan Ramirez and Ken Prestwich of Sandia National Laboratory during the design phase of this project is also gratefully acknowledged.

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References

[1] R.B. Miller, K.R. Prestwich, J.W. Poukey, and S.L. Shope, J. Appl. Phys. 51, 3506 (1980).

[2] R.J. Adler, R.B. Miller, K.R. Prestwich, and D.L. Smith, Rev. Sci. Instrum. 54, 940 (1983).

[3] J.C. Martin as discussed in R.B. Miller, "An Introduction to the Physics of Intense Charged Particle Beams" (Plenum Press, New York, NY, 1982).

[4] D.D. Hinshelwood, NRL Memorandum Report No. 5185, dtd. Nov. 21, 1983.